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Mesoscale Convective Systems during SCSMEX: Simulations with a Regional Climate Model and a Cloud-Resolving Model

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1. Introduction

The South China Sea Monsoon Experiment (SCSMEX) was conducted in May-June 1998. One of its major objectives is to better understand the key physical processes for the onset and evolution of the summer monsoon over Southeast Asia and southern China (Lau *et al.* 2000). Multiple observation platforms (e.g., soundings, Doppler radar, ships, wind profilers, radiometers, etc.) during SCSMEX provided a first attempt at investigating the detailed characteristics of convection and circulation changes associated with monsoons over the South China Sea region. SCSMEX also provided precipitation derived from atmospheric budgets (Johnson and Ciesielski 2002) and comparison to those obtained from the Tropical Rainfall Measuring Mission (TRMM).

In this paper, a regional climate model and a cloud-resolving model are used to perform multi-day integrations to understand the precipitation processes associated with the summer monsoon over Southeast Asia and southern China. The regional climate model is used to understand the soil-precipitation interaction and feedback associated with a flood event that occurred in and around China's Yantz River during SCSMEX. Sensitivity tests on various land surface models, cumulus parameterization schemes (CPSs), sea surface temperature (SST) variations and midlatitude influences are also performed to understand the processes associated with the onset of the monsoon over the S. China Sea during SCSMEX.

Cloud-resolving models (CRMs) use more sophisticated and physically realistic parameterizations of cloud microphysical processes with very fine spatial and temporal resolution. One of the major characteristics of CRMs is an explicit interaction between clouds, radiation and the land/ocean surface. It is for this reason that GEWEX (Global Energy and Water Cycle Experiment) has formed the GCSS (GEWEX Cloud System Study) expressly for the purpose of improving the representation of the moist processes in large-scale models using CRMs. The Goddard Cumulus Ensemble (GCE) model is a CRM and is used to simulate convective systems associated with the onset of the South China Sea monsoon in 1998. The GCE model includes the same land surface model, cloud physics, and radiation scheme used in the regional climate model. A comparison between the results from the GCE model and regional climate model is performed.

2. Model Description

2.1 Regional Climate Model

A Regional Land-Atmosphere Climate Simulation (RELACS) System is being developed and implemented at NASA Goddard Space Flight Center. One of the major goals of RELACS is to use a regional-scale model with improved physical processes, in particular land-related processes, to understand the role of the land surface and its interaction with convection and radiation as well as the water and energy cycles in Indo-China, the South China Sea (SCS), China, N. America and S. America.

Parameters/Processes	**Penn State/NCAR MM5**
Vertical Coordinate	sigma-p (z)
Explicit Convective Processes	1-2 class water & 1-2 class ice ***3 ice scheme****
Implicit Convective Processes	Cumulus Parameterization Schemes
Numerical Methods	Leapfrog in Time and 2nd Order Scheme in Advection for both Scalar and Dynamic Variables ***Off-line positive definite transport****
Initialization	*Goddard DAO**, NCEP and ECMWF Analyzed (and/or Bogus) Data
FDDA	Nudging/Adjoint ***Rainfall****
Radiation	Emissivity Method in LW ***Goddard k-distribution and four-stream discrete-ordinate scattering (8 bands)****
Sub-Grid Diffusion	Smagorinski
Planetary Boundary Processes	Blackadar PBL or Dry Convective Adjustment *TKE (PSU)**
Topography	Sigma-p (z)
Two-Way Interactive Nesting	Traditional but with Monotonic Interpolation
Surface Energy Budget	Force-restore Method or *7-Layer Soil Model (PLACE)**

Table 1 ***Characteristics of the PSU/NCAR MM5. Processes modified by the Goddard Mesoscale Modeling and Dynamics Group are marked with an *.***

The Penn State/NCAR MM5 atmospheric modeling system, a state of the art atmospheric numerical model designed to simulate regional weather and climate, has been successfully coupled to the Goddard Parameterization for Land-Atmosphere-Cloud Exchange (PLACE) land surface model. PLACE allows for the effects of vegetation, and thus important physical processes such as evapotranspiration and interception are included. The PLACE model incorporates vegetation type and has been shown in international comparisons to accurately predict evapotranspiration and runoff over a wide variety of land surfaces. The coupling of MM5 and PLACE creates a numerical modeling system with the potential to more realistically simulate the atmosphere and land surface processes including land-sea interaction, regional circulations such as monsoons, and flash flood events. In addition, the Penn State/NCAR MM5 atmospheric modeling system has been: (1) coupled to the Goddard ice microphysical scheme, (2) coupled to a turbulent kinetic energy (TKE) scheme, (3) coupled to the Goddard radiation scheme, (4) modified to ensure cloud budget balance, and (5) has incorporated initialization with the Goddard EOS data sets at the NASA/Goddard Laboratory for Atmospheres. Table 1 shows the major characteristics of MM5.

RELACS is used to simulate the onset of the South China Sea monsoon in 1986, 1997 and 1998. RELACS is also used to understand the soil-precipitation interaction and feedback associated with a flood event that occurred in and around China's Yantz River during 1998. The model is typically run within a domain covering 6000-8000 km by 6000-8000 km using interactive nesting techniques with multiple grid refinements and a nesting ratio of 3:1.

2.2 *Cloud-Resolving Model*

The Goddard Cumulus Ensemble (GCE) Model, a cloud-resolving model, has been developed and improved at NASA/Goddard Space Flight Center over the past two decades. Novel characteristics of the GCE model are the explicit representation of warm rain and ice microphysical processes, and their complex interactions with solar and infrared radiative transfer processes, and with surface processes. The GCE model is being linked with other physical models such as: passive microwave radiative transfer and spaceborne precipitation radar models for the purposes of developing and improving retrieval algorithms of precipitation and latent heat release, and a photo-chemistry model to assess the impact of vertical transport and mixing of important trace species on O_3 production/reduction processes. More than 90 GCE modeling papers were published over the last two decades (Tao 2002). Table 2 shows the GCE model's major characteristics.

The equations that govern cloud-scale motion (wind) are anelastic by filtering out sound waves. The subgrid-scale turbulence used in the GCE model is based on work by Klemp and Wilhelmson (1978). In their approach, one prognostic equation is solved for subgrid kinetic energy, which is then used to specify the eddy coefficients. The effect of condensation on the generation of subgrid-scale kinetic energy is also incorporated in the model (see Soong and Ogura 1980; Tao and Soong 1986 for details). The cloud microphysics include a parameterized Kessler-type two-category liquid water scheme (cloud water and rain), and a parameterized Lin *et al.* (1983) or Rutledge and Hobbs (1984) three-category ice-phase scheme (cloud ice, snow and hail/graupel) (see Tao and Simpson 1993 and Tao *et al.* 2002 for a detailed description of the cloud microphysics). Shortwave (solar) and longwave (infrared) radiation parameterizations are also included in the model (Tao *et al.* 1996). The TOGA-COARE bulk flux algorithm (Fairall *et al.* 1995) is linked to the GCE model to calculate the surface fluxes (Wang *et al.* 1996, 2002). All scalar variables (potential temperature, mixing ratio of water vapor, turbulent coefficients, and all five hydrometeor classes) use forward time differencing and a positive definite advection scheme with a non-oscillatory option (Smolarkiewicz and Grabowski 1990). The dynamic variables, u, v and w, use a second-order accurate advection scheme and a leapfrog time integration (kinetic energy semi-conserving method). Details of the model description and tests can be found in Tao and Simpson (1993) and Tao *et al.* (2002).

Parameters/Processes	GCE Model
Vertical Coordinate	z
Explicit Convective Processes	2 class water & 2 moment 4 class ice Spectral Bin Microphysics
Implicit Convective Processes	Betts & Miller or Kain & Fritsch
Numerical Methods	Positive Definite Advection for Scalar Variables; 4-th Order for Dynamic Variables
Initialization	Initial Condition with Forcing from Observations/Large-Scale Model
FDDA	Nudging
Radiation	k-distribution and four-stream discrete-ordinate scattering (8 bands) Explicit Cloud-Radiation Interaction
Sub-Grid Diffusion	TKE (1.5 order)
Topography	Sigma-z*
Two-Way Interactive Nesting	Radiative-Type
Surface Energy Budget	Force-restore Method 7-Layer Soil Model (PLACE) TOGA COARE Flux Module

Table 2 Characteristics of the Goddard Cumulus Ensemble Model.

2.3 Water Budget Analysis

To quantify the moisture processes, the regional scale model's hydrology budget was calculated horizontally and vertically integrating the continuity equation for atmospheric moisture around a rectangular domain, which yields:

$$W=FW-FE+FS-FN+E-P-R$$

Where W is the total change of atmospheric water vapor which is generally a small term; FW, FE, FS, and FN are the vertically integrated moisture fluxes along the western, eastern, southern, and northern boundaries of the budget calculation domain, respectively; $Q=FW-FE+FS-FN$ is the total moisture convergence in the domain; E is the total surface evaporation, P is the total precipitation; and R is the residual term.

3. Results

3.1 Regional Climate Model Simulations

(a) South China Sea (1986, 1997 and 1998)

Prior to SCSMEX (1998), a pilot study was performed to determine the model design (i.e., size of domain, grid size), physical processes and initial data that are needed for the successful simulation of convective activity over Indo-China and the South China Sea. The MM5 with two nested domains (60 and 20 km horizontal resolution) was used to simulate convective activity over Indo-China and the South China Sea, during the monsoon season, from May 6 to May 20, 1986. Sensitivity tests indicated that a large domain was needed for good simulations (Fig. 1). The model results captured several dominant observed features, such as twin cyclones, a depression system over the Bay of Bengal, strong south-westerly winds over Indo-China before and during the onset of convection over the SCS, and a vortex over the SCS. Two additional MM5 runs with different land process models, Blackadar and MRF, were performed, and their results are compared to the run with PLACE. The results indicate that the MM5 results using PLACE and Blackadar are in very good agreement, but the results using MRF do not contain the south-westerly wind over Indo-China prior to the onset of convection over the SCS. However, no surface rainfall estimates/observations were available for model validation for the pilot case.

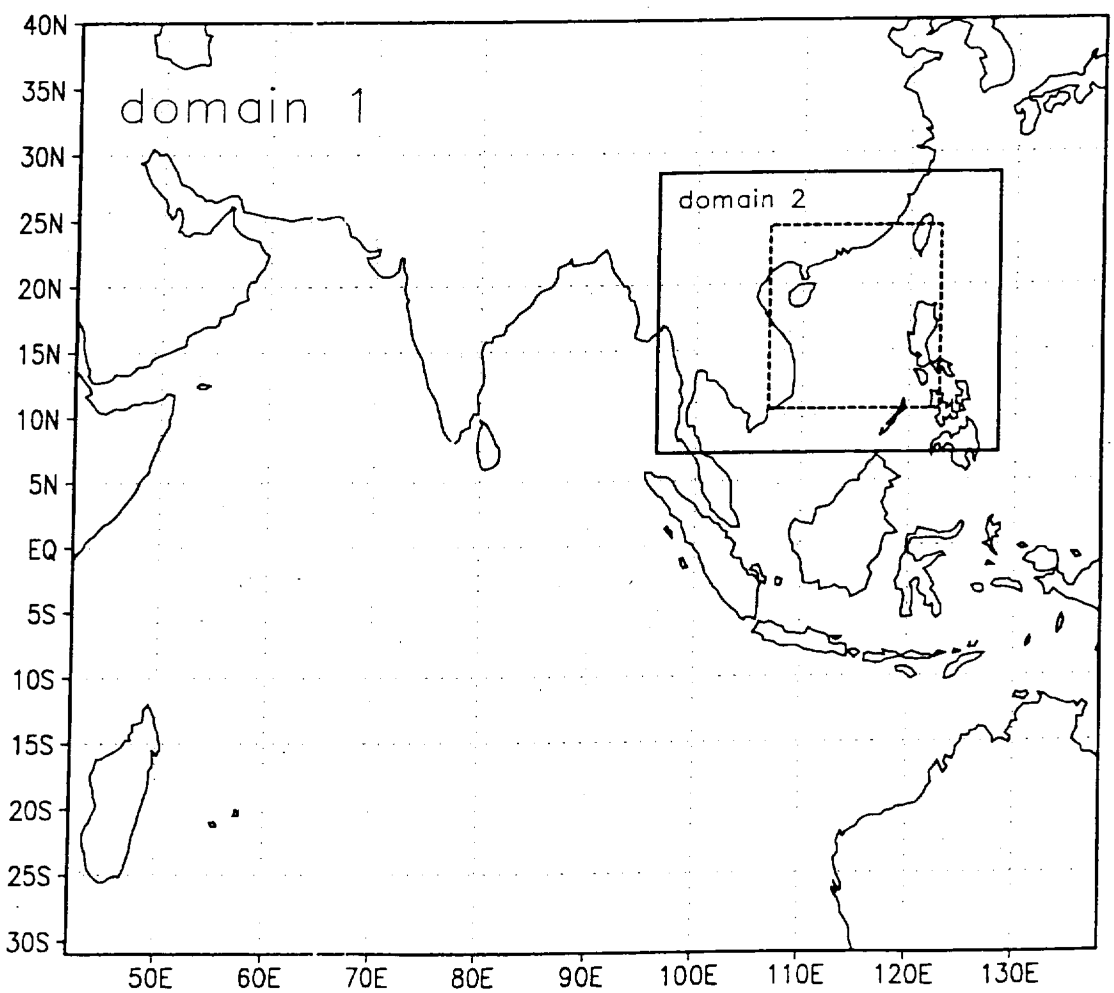

Fig. 1 Nested configuration used by the model. Horizontal resolutions for domains 1 and 2, are 60 and 20 km, respectively. The water budget is calculated over the domain marked with dashed lines.

The onset of the South China Sea monsoon (SCSM) in 1997 and 1998 has also been studied using RELACS. In both 1997 and 1998, signals for the onset of the monsoon were strong (in other cases, 1999 for example, the signal is very week). The pre-onset is also associated with the development of a "double cyclone" in the Bay of Bengal as with the pilot case (1986). The northern cyclone strengthened and the southern dissipated. When the northern cyclone reached the northwest part of the Indo-China Peninsula, it spun up a strong southwestly flow across the peninsula. The onset of the monsoon in both cases coincided with the arrival of the strong southwest winds in the South China Sea.

In 1998, beginning on May 15, strong convection occurred around the coast of southern China associated with a cold front pushing to the southeast to the northern part of the SCS. Convection intensified and rainfall peaked on May 17. The southeast circulation only penetrated into the western part of the SCS with the western part of the SCS still under the control of a West Pacific high-pressure system. By the 21st of May, the SCS was completely occupied by the southwest circulation. By the 23rd of May, a large-scale wind vortex became established over the northern part of the SCS. This vortex then propagated southeastward to the southern part of the SCS.

The onset of the 1997 monsoon is different from the one in 1998 in the following ways. First, the penetration of southwesterly winds into the SCS is much stronger. The onset is also much more abrupt than in 1998. The strong southwestly winds completely pushed the west Pacific high-pressure system out the SCS region during the first two days of the onset (May 19-20). Secondly, the northern cold front from southern China was also stronger than that in 1998. Third, the precipitation was much more intense in 1997 during the onset period. Due to the stronger circulation and much quicker onset, the water budget for the region was also very different.

A series of two-week numerical experiments have been carried out to study the effects of local land-cover changes on convective activity over Indo-China and the South China Sea, during the monsoon season, from May 18 to May 29, 1997. The temporal variation of simulated rainfall compared well with Global Precipitation Climatology Project (GPCP)[1] estimates (Fig. 2a). The

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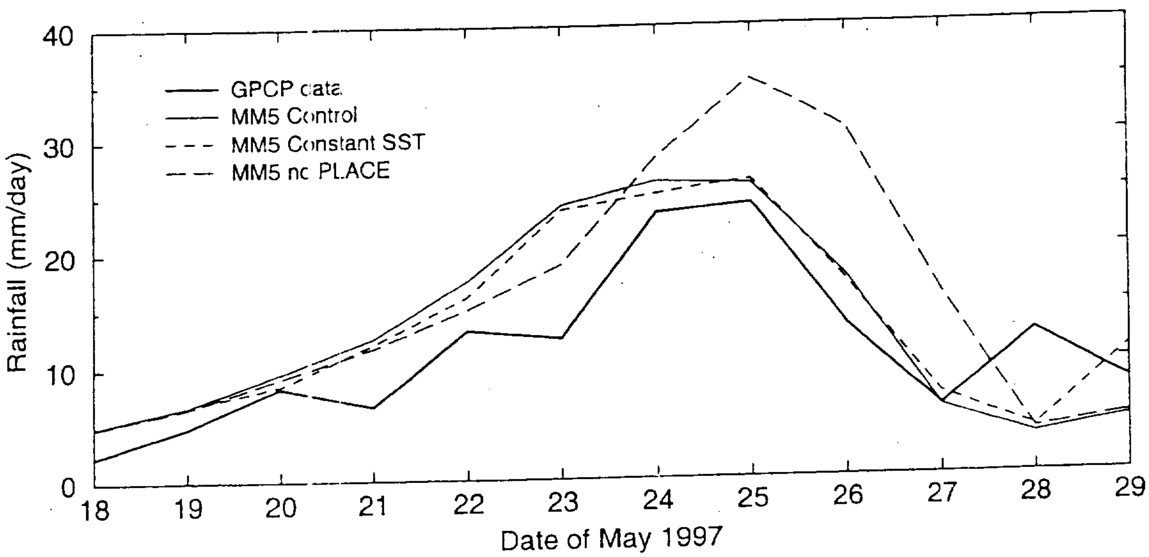
1 This data set is the merged satellite-gauge rainfall estimate. The satellite data includes Special Sensor Microwave/Imager (SSM/I) and infrared (IR) precipitation estimates from geostationary satellites and other low-earth orbit estimates from the Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS). The gauge data are assembled and analyzed by the Global Precipitation Climatology Center of Deutscher Wetterdienst and by the Climate Prediction Center of the NOAA. The version of data used here has a spatial resolution of 1 x 1 and a daily time resolution.

maximum rainfall that occurred on May 24 and 25 was well simulated. The run without PLACE produced more rainfall compared to GPCP, and its maximum occurred on May 25. Sea surface temperature (SST) variation[2] only has a small impact on rainfall.



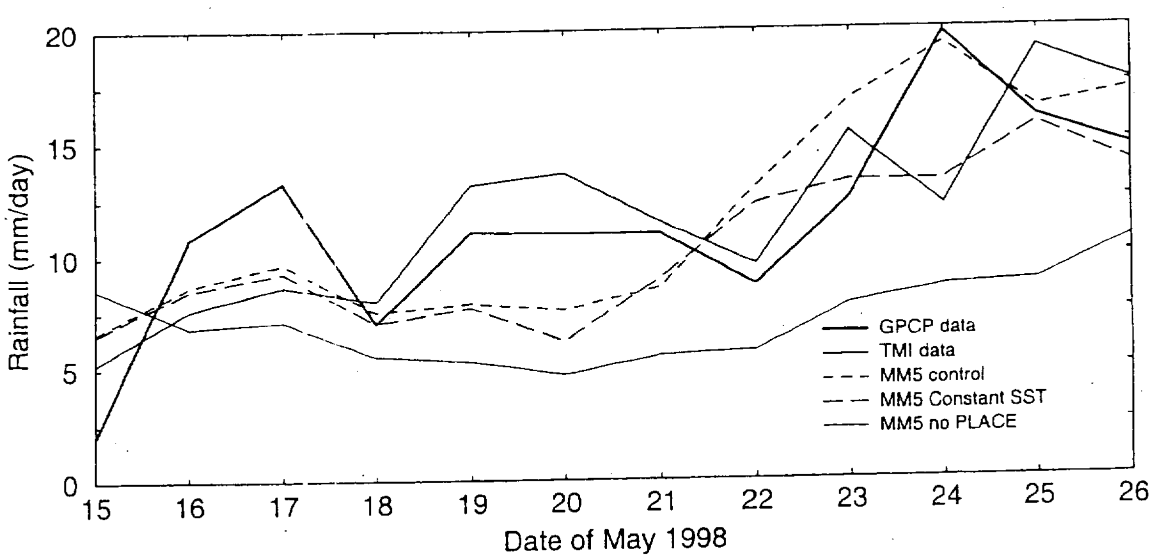
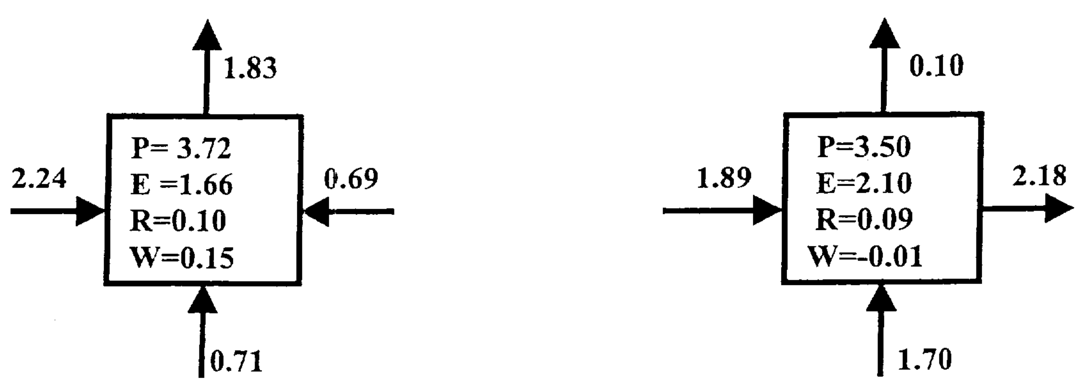


Fig. 2 (a) Daily rainfall (in mm day-1) averaged over the South China Sea region during May 18 to 29, 1997. (b) is the same as (a) expect for during 15 to 26, 1998.

2 For the sensitivity test, SST is not allowed to vary with time and kept the same as on the first day of integration (May 18).

The Tropical Rainfall Measuring Mission (TRMM) was launched on November 1997. For 1998 case, the RELACS simulated rainfall can be compared with TRMM[3] and GPCP rainfall products. Both satellite-derived rainfall products showed several peaks in rainfall over the S. China Sea in May 1998 (Fig. 2b). Both also showed daily rainfall increasing with time. In general, the RELACS system captured these observed features. For example, the model correctly simulated the onset of the SCSM on May 17, with the build up of westerlies over the northern part of the Indian Ocean, and the movement of strong convection and precipitation from the Bay of Bengal to the South China Sea. These features were also observed and simulated by MM5 in 1986. In addition, the model results are in very good agreement with TRMM rainfall during the first 4 days of integration and with GPCP during the last 5 days of integration. The run without PLACE does not capture the observed multiple rainfall peaks.

The water and energy cycles (surface precipitation and its associated latent heat release and surface fluxes) were calculated to assess the role of the atmosphere and the land-surface components responsible for the development of the monsoon for the 1997 and 1998 cases. The results indicated that there were no significant differences in terms of evaporation, rainfall and precipitation between the two cases (Fig. 3). One of the major differences is that significant moisture was transported to the northern boundary (toward S. China) in 1998 but not in 1997. Another difference is that the eastern Pacific was a moisture source in 1998 but a sink in 1997. There was a greater contribution from the equatorial region in 1997.



a) Year 1998 **b) Year 1997**

Fig. 3 Water budget for the South China Sea monsoon onset area (10-24 N, 108-123 E). Units are 10^{13} Kg/day. P is precipitation E is evaporation fluxes, R is residual, and Q is total moisture fluxes.

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3 The rainfall is based on the Goddard Profiling (GPROF) algorithm for microwave sensing. This rainfall data has higher spatial and time resolutions (0.5 x 0.5, hourly) compared to the GPCP rainfall data. However, the TMI data has large blank gaps due to the nature of the TRMM satellite orbit..

(b) Central China (June 1998)

The RELACS has also been used to simulate the Yantze River flood in June 1998 (from June 13 to 19). The model results showed that there are two major physical processes associated with Mei-Yu precipitation over central China (Qian *et al.* 2002). The first one is the local effect of the land surface. Two experiments, one allowing full interaction between precipitation and surface evaporation in the PLACE and the other one not, were conducted. In the second experiment (NF), the precipitation is assumed to completely run off immediately without having any impact on soil moisture or vegetation. The interaction between surface evaporation and precipitation can determine the Mei-Yu front's location (Fig. 4). Previous upstream precipitation can produce strong evaporative fluxes and allow MM5 to better predict the Mei-Yu front. The second major process is to examine the remote moisture sources that physically determine the Mei-yu precipitation/flood. Sensitivity tests, reduction of atmospheric water vapor fluxes from the western, southern and eastern lateral boundary, were performed. Results indicated that the Mei-Yu precipitation is basically determined by the moisture transport of the southwesterly low level jet (LLJ) from Indo-China. There is very little impact from moisture transported from the South China Sea and the Pacific Ocean.

Water budgets were calculated over four rectangular domains A, B, C, and D, representing western China, the Yantze River Valley, southern China and the South China Sea, and the Indo-China Peninsula, respectively (Fig. 5). The total atmospheric water vapor change W is small. The change in cloud water storage is included as part of the residual term R. For domain B (the Yangtze River Valley), the total precipitation P is 144; the surface evaporation E is 45; the total moisture fluxes FS, FW, FN, and FE are 280, 450, -65, and 689, respectively. Thus the moisture convergence Q is 105. For the sensitivity test (W80) that reduced the moisture fluxes from western lateral boundary by 20%, FW for domains D (the Indo-China Peninsula) and A (western China) are reduced by 54 and 35, respectively, and FW for domain is reduced by 51. The precipitation over B is reduced substantially by 38 (about 1/4 of control run). No flood was produced in the Yangtze River Valley if the moisture fluxes were further reduced to 50% from model's western boundary. For the sensitivity test (S80) that reduced the moisture fluxes from southern lateral boundary by 20%, FS for domains C (southern China and the South China Sea) and D are reduced by 73 and 49, respectively, and FS for the Yangtze River Valley is reduced by 25. But, the precipitation over the Yangtze River Valley is only reduced by 4. Thus, although the moisture transport from the tropics is quite strong, its impact on Mei-Yu precipitation is not significant.

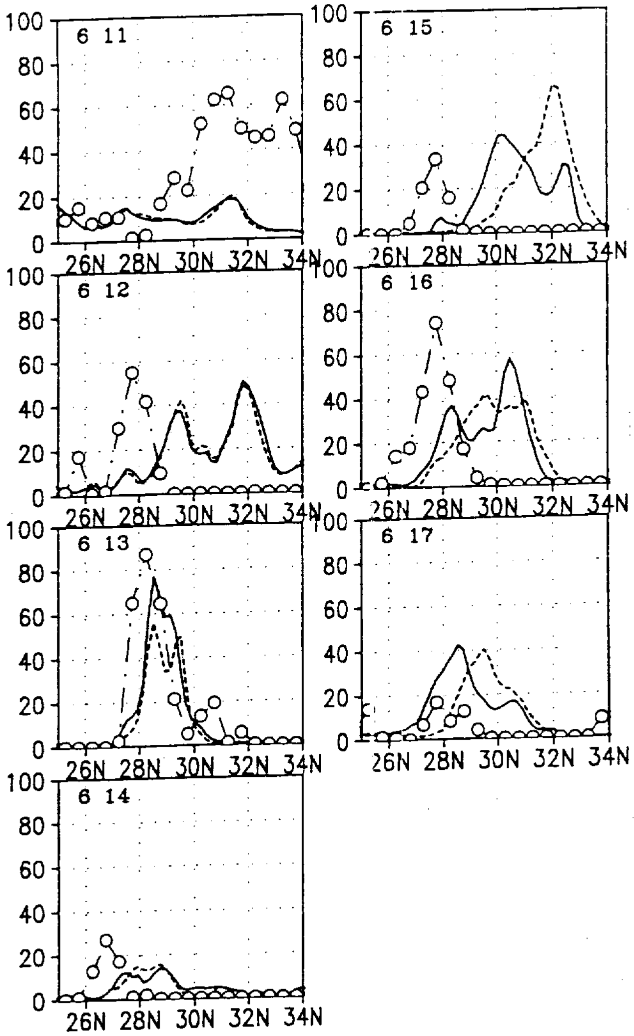

Fig. 4 *Meridional distribution of daily rain rate (mm day^{-1}), averaged from 11E to 121 E for the TRMM observed (dot-dash-circle), control run (solid) and NF (dash).*

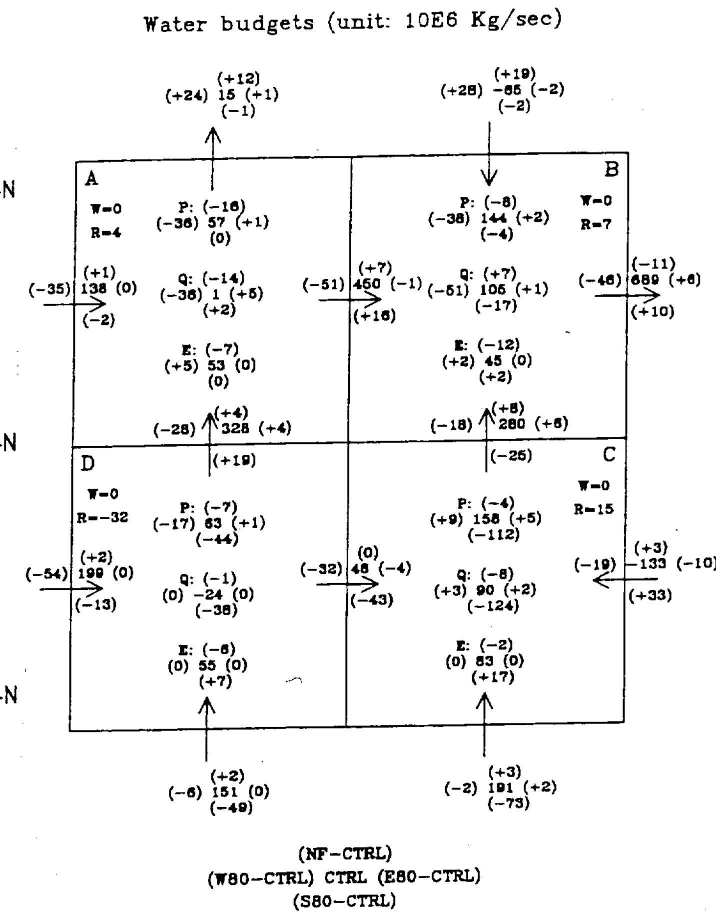

Fig. 5 *Water budget in domains A, B, C and D, representing western China, the Yangtze River Vally and southern China, the South China Sea, and the Indo-China Peninsula, respectievely. Budegt components P, E, Q, W and R defined in Equation (1). The units are 10^6 Kg/s.*

In addition, the model results are very sensitive to the cumulus parameterization schemes used in the MM5. The Betts and Miller scheme produced too much rainfall over the East Coast of China. The Kain-Fritsch schemes, on the other hand, simulated rainfall in good agreement with observations.

3.2 *Cloud-resolving model simulations*

The GCE model is used to simulate convective systems for two SCSMEX convective periods, May 18-26 (prior to and during the monsoon) and June 2-11 (after the onset of the monsoon)

1998 (Tao *et al.* 2002). Observed large-scale advective tendencies (or forcing) for temperature, water vapor mixing ratio, and horizontal momentum are used as the main large-scale forcing in governing the GCE model in a semi-prognostic manner (Soong and Ogura 1980; Soong and Tao 1980; Tao and Soong 1986). The main feature of this approach is that ensembles of clouds can be generated by the "*observed-prescribed forcing*". This type of cloud-resolving modeling was used in many recent modeling studies to study TOGA COARE and GATE convective systems (Krueger 1988, Grabowski *et al.* 1998, Wu and Randall 1996, Wu *et al.* 1998, Donner *et al.* 1999). Please see reviews by Tao (2002) and Johnson *et al.* (2002).

The temporal variation of the GCE model simulated rainfall is in very good agreement with that estimated from soundings (Fig. 6). The probability distributions of simulated rainfall for these SCSMEX cases and that estimated by soundings are also in good agreement for both cases. For example, a bimodal distribution of rainfall for the May case is well simulated by the model. In contrast, there is only a single peak for both simulated and observed distributions for the June case. The good agreement is mainly caused by the fact that the GCE model was forced by large-scale tendencies in temperature and water vapor computed from the sounding network. When the imposed large-scale advective forcing cools and moistens the environment, the model responds producing clouds through condensation and deposition. The fall out of large precipitation particles produces rainfall at the surface. The larger the advective forcing, the larger the microphysical response (rainfall) the model will produce (Soong and Tao 1980; Tao and Simpson 1984). On the other hand, the model will not produce any cloud or rainfall when the imposed large-scale advective forcing heats and dries the atmosphere. The rainfall amounts simulated by the GCE model and estimated by the TRMM PR, the TMI and from soundings are quite different. But, they all indicate that less rainfall occurs in the May case than in the June case. Surprisingly, the model under-estimated rainfall by 14% and 20%, respectively, for the May and June cases compared to that calculated based on soundings. In other previous GCE model simulations, the rainfall amount simulated by the GCE model and estimated by soundings is usually in excellent agreement (less than 0.5%) with each other (i.e., Johnson *et al.* 2002). The GCE-model-simulated rainfall for June is in very good agreement with the TRMM PR and GPCP. The TMI-estimated rainfall is about twice that estimated by the GCE and PR.

Similarities and differences between precipitation processes that occurred prior to and that which occurred after the onset of the monsoon can be identified by examining the water vapor budget (Table 3). In both runs, the largest two terms in the water vapor budget are net condensation (heating) and imposed large-scale forcing (cooling). These two terms are opposite in sign, however. Soong and Tao (1980) performed experiments with different magnitudes of large-scale forcing and found that the larger the large-scale forcing (cooling/moistening), the larger the net condensation (heating/drying). They hypothesized that the effect of cloud microphysics is simply a response to the "imposed large-scale forcing in temperature and water vapor". The

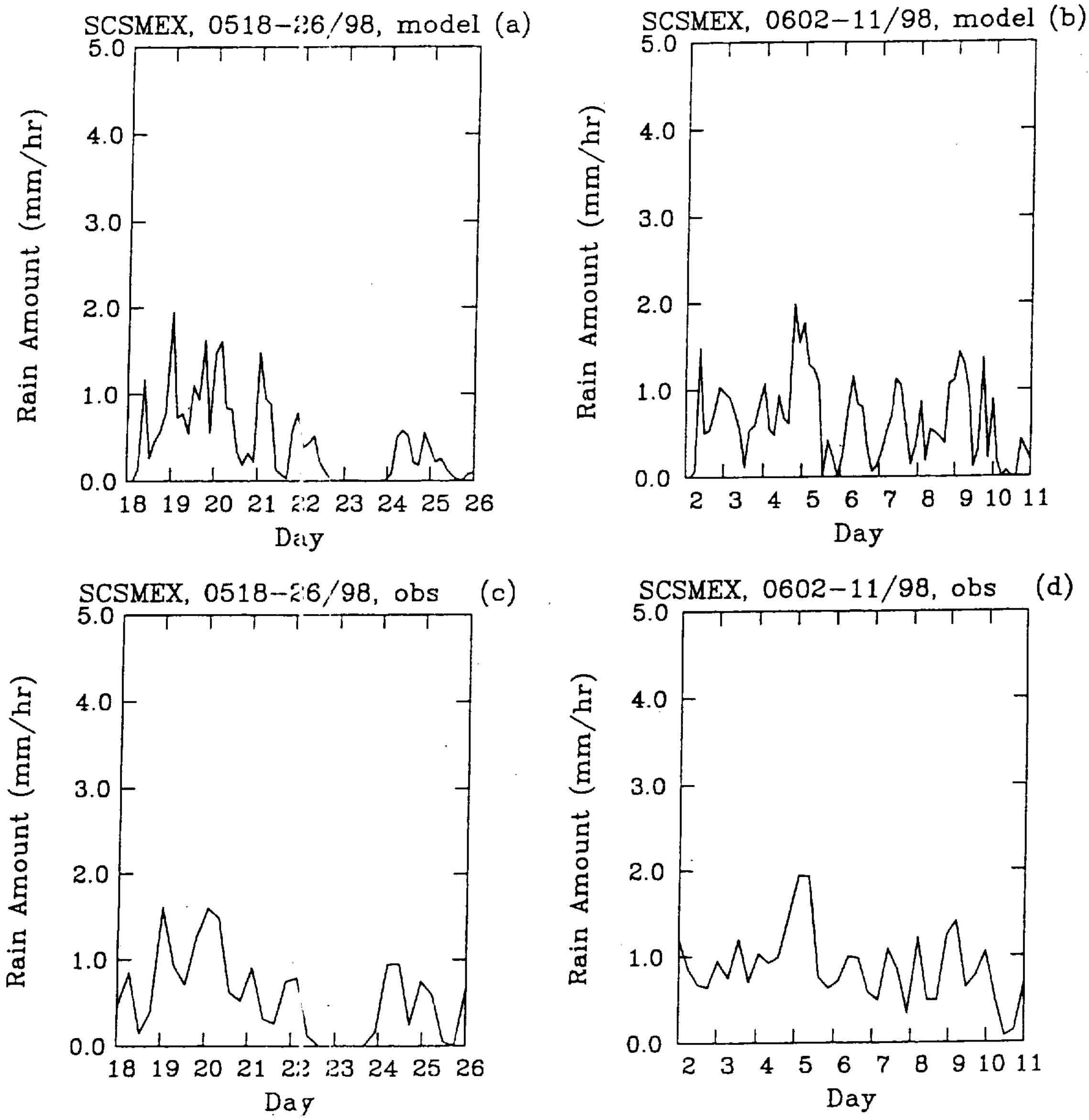

Fig. 6 Time-sequence of the GCE-model-estimated domain-mean surface rainfall rate (mm h^{-1}) for (a) May 18-26 and (b) June 2-11, 1998. (c) and (d) are rainfall estimates using the Q_2 budget.

results also show there are more latent heat fluxes prior to the onset of the monsoon. However, more rainfall was simulated after the onset of the monsoon. This is because large-scale advective moisture from the lateral boundaries is almost twice as large after the onset of the monsoon. The radiative forcing is quite similar between these two cases.

	d(Qv)/dt	Net Condensation	Large-scale Forcing	Latent Heat Fluxes
May18 - May 26	0.05	-11.23	9.81	1.47
June 2 – June 11	1.21	-16.45	16.84	0.82

Table 3 *Water budgets for the 18-26 May and 2-11 June 1998 cases. Net condensation is the sum of condensation, deposition, evaporation and sublimation of cloud. Large-scale forcing is the imposed large-scale advective effect on water vapor, and $L_v d(q_v)$ is the local time change of water vapor. Units are in $W\ m^{-2}$.*

3.3 *Precipitation Efficiency*

The large-scale precipitation efficiency in the simulations can be defined as (1) the ratio of the total rainfall to the large-scale water vapor transported into the domain plus latent heat flux (L-PE-1), or (2) the ratio between the total rainfall to the large-scale water vapor transported into the domain (L-PE-2). The larger the difference between these two large-scale precipitation efficiencies, the more latent heat flux (or evaporation flux) contributes to the rainfall. The definition of these precipitation efficiencies is very different from several definitions of storm-scale precipitation efficiency [see Ferrier *et al.* (1996) for a detailed review on precipitation efficiency associated with storms].

	D(Qv)/dt	Precipitation (Rainfall)	Large-scale Forcing	Latent Heat Fluxes (Evaporation)	L-PE-1 L-PE-2
June 1998 China		144	105	45	0.96/1.37
June 1998 S. China Sea		158	90	83	0.91/1.76
May 1997 S. China Sea	-0.01	3.50	1.31	2.10	1.03/2.67
May 1998 S. China Sea	0.15	3.72	1.81	1.66	1.07/2.06
May 1998 CRM	0.024	10.55	9.01	1.56	0.99/1.17
June 1998 CRM	1.678	15.26	16.13	0.81	0.90/0.95

Table 4 *Large-scale precipitation efficiencies calculated from regional climate model simulations and cloud-resolving model simulations.*

Table 4 shows the two large-scale precipitation efficiencies from the regional climate model simulations for 1997 and 1998, and the cloud-resolving model simulations for 1998. The results indicated that the L-PE-1 is close to one for all cases and for both models. This implies that the local change of water vapor over S. China and the S. China Sea does not vary much before and after convective events. However, the L-PE-2 is larger in the regional climate simulations than in the cloud-resolving model simulations. This result indicates the latent heat fluxes (or evaporation) have more of an impact on precipitation in the regional climate model simulations. The results also indicate that the impact of latent heat fluxes on precipitation processes is smaller for S. China than over the S. China Sea in the regional climate simulations. This is because the latent heat fluxes over land have a smaller contribution to precipitation than those from the ocean.

4. Summary

RELACS has been used to simulate the onset of the South China Sea monsoon in 1986, 1997 and 1998. Sensitivity tests on various land surface models, cumulus parameterization schemes (CPSs), sea surface temperature (SST) variations and midlatitude influences have been performed. These tests have indicated that the land surface model has a major impact on the circulation over the S. China Sea. CPSs can effect the precipitation pattern while SST variation can effect the precipitation amounts over both land and ocean. RELACS has also been used to understand the soil-precipitation interaction and feedback associated with a flood event that occurred in and around China's Yantz River during 1998. The exact location (region) of the flooding can be effected by soil-rainfall feedback.

The GCE model was used to simulate convective systems for two SCSMEX convective periods, May 18-26 (prior to and during the monsoon) and June 2-11 (after the onset of the monsoon), 1998. The GCE-model-simulated rainfall captured the temporal variation quite well in both cases compared to the sounding estimated rainfall. A bimodal distribution of rainfall for the May case and a single peak for the June case are well simulated by the GCE model. The rainfall amounts simulated by the GCE model and estimated by the TRMM PR, the TMI and from soundings are quite different. The GCE-model-simulated rainfall is in closer agreement with the TRMM PR than the soundings and the TMI. TMI-estimated rainfall is about twice that estimated by the GCE and PR. A detailed study to determine the reasons for the differences in rainfall amounts between the different measurements is underway through the TRMM project. The results show there are more latent heat fluxes prior to the onset of the monsoon. However, more rainfall was simulated after the onset of the monsoon. Small differences in the precipitation efficiency between the two periods is noted.

This modeling study indicates the latent heat fluxes (or evaporation) have more of an impact on precipitation processes and rainfall in the regional climate model simulations than in the cloud-resolving model simulations. Research is underway to determine if the difference in the grid sizes or the moist processes used in these two models is responsible for the differing influence of surface fluxes on precipitation processes.

5. Acknowledgement

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